DEVELOPMENT OF A GROUND TRUTH DATABASE FOR IMPROVEMEMENT OF CTBT MONITORING IN THE EASTERN MEDITERRANEAN REGION

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ABSTRACT

A reliable Ground Truth (GT) database is crucial to improve the monitoring of small seismic events in the Middle East. Therefore, the Geophysical Institute of Israel (GII), Bogazici University, Kandilli Observatory and Earthquake Research Institute, Istanbul (Turkey) (KOERI), TUBITAK Marmara Research Center, Earth and Marine Sciences Research Institute, (Turkey) (EMSRI) and the Geological Survey Department of Cyprus (GSDC) joined their efforts to develop a database using seismic data from the national networks and arrays advantageously placed in the eastern Mediterranean region.

The elaborated GT database includes: 1) GT2-GT5 data for earthquakes and aftershocks that are well constrained by dense local and portable networks; 2) GT2 data of large routine quarry blasts supplied by blast pattern parameters; and 3) GT0 data for controlled routine quarry blasts and special design calibration explosions conducted previously and during project duration, including detailed blast pattern design.

At the first stage of the project, we elaborated the database for calibration of the International Monitoring System (IMS) stations EIL and MRNI relative to local GT events, well located by the Israel Seismic Network (ISN) stations. We collected 27 GT0 events (including the three Dead Sea calibration explosions in November 1999) and 23 GT2 industrial explosions from quarries in the Negev and Galilee (local magnitude M_L = 2.7-3.1); all the explosions are recorded with a high signal-to-noise ratio (SNR) up to 250 km. About 20 accurately located (GT2-GT5 rank) earthquakes in Israel (M_L > 3) were selected.

Next, we accumulated travel times data from earthquakes for correction of the travel-time models from specific areas to the IMS stations within the radius of 2000 km of the chosen seismic networks. After screening of numerous candidate events, we selected 21 earthquakes from different eastern Mediterranean sites within the footprint of the local networks: a) 6 earthquakes of M_L >4 located between the Cypriot Seismic Network and the ISN (GT5 rank); b) 7 Adana-Ceyhan earthquakes (M_L > 4) and 8 Izmit and Bolu-Duzce earthquakes (M_L > 4.5), well covered by the Turkish networks together with portable stations (GT2-GT5 rank). All selected earthquakes were carefully screened, relocated, and checked according to the appropriate GT criteria.

The accumulated GT events were also used to improve event location: a) event relocation based on evaluated travel-time residuals; b) estimation of corresponding 90% confidence ellipsoids; c) verification by the Monte-Carlo simulation. The collected earthquake/explosion data will be used for: a) mapping travel time residuals, azimuth residuals and regional phase attenuation, b) upgrading of the Robust Location Procedure to an automatic bulletin producer; c) development of the grid search procedure for location and confidence volume estimation; d) modification and testing of advanced seismic processing methods: 1) maximum likelihood beamforming applied to the BRAR and MRNAR arrays; and 2) regional multi-station spectral and kinematic discriminants to be adapted to the Turkish Seismic Network.

KEY WORDS: ground truth database, IMS station calibration, eastern Mediterranean, event relocation

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OBJECTIVE

The main objective of the project is to characterize and enhance the CTBT monitoring potential of small events in the eastern Mediterranean area, based on jointly collected GT0-GT5 database of earthquakes and chemical explosions and on development and implementation of improved signal processing techniques.

RESEARCH ACCOMPLISHED

On the first stage the main effort for the GII (Israel), the KOERI/EMSRI (Turkey), and the GSDC (Cyprus), was to elaborate a joint database of waveforms and source parameters: 1) GT5 dataset of earthquakes (aftershocks), located within the network foot-print, with an estimated small location error (Pinsky et al., 2001); 2) GT0-GT2 waveform dataset for controlled routine quarry blasts and calibration explosions of special design (Dead Sea, Negev and Galilee). The database was elaborated by screening local bulletins and seismic records of national stations.

Earthquakes and large aftershocks (GT2-GT5) jointly observed by seismic stations in Israel, Cyprus and Turkey.

"Israeli" earthquakes

For the period 1995-2001 we screened 21 earthquakes of magnitude $M_L > 3$ (Fig. 1) located within the Israel Seismic Network (station azimuth gap<210°), which were checked to fit the GT5 criteria (Firbas, 2001). Most of the events are observed also by the Cypriot Seismic Network (CSN). Several earthquakes with M_L>3.5 are expected to be detected by the Cilician Network (Southern Turkey) and we are now looking for their data.

The source parameters of the selected events and their waveform data from the CSN and the ISN are now available. Some of the earthquakes are observed by the IMS stations EIL and MRNI, installed in 1996 and 1997 respectively, and the records will be used in the project for regional source characterization and calibration of the stations. All of the events were relocated to more accurate and more reliable solutions using relevant weights. Corresponding 90% confidence ellipsoids were estimated and checked by the Monte-Carlo simulation, an example is presented in Fig. 2.

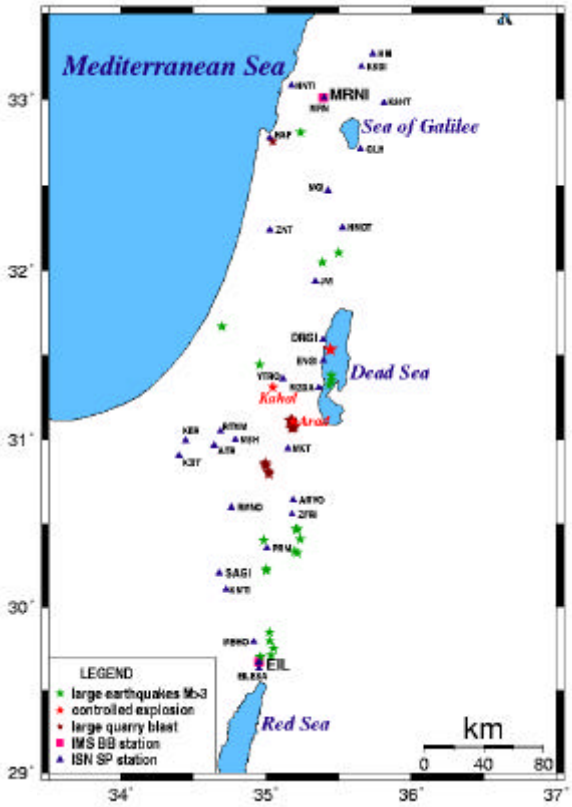
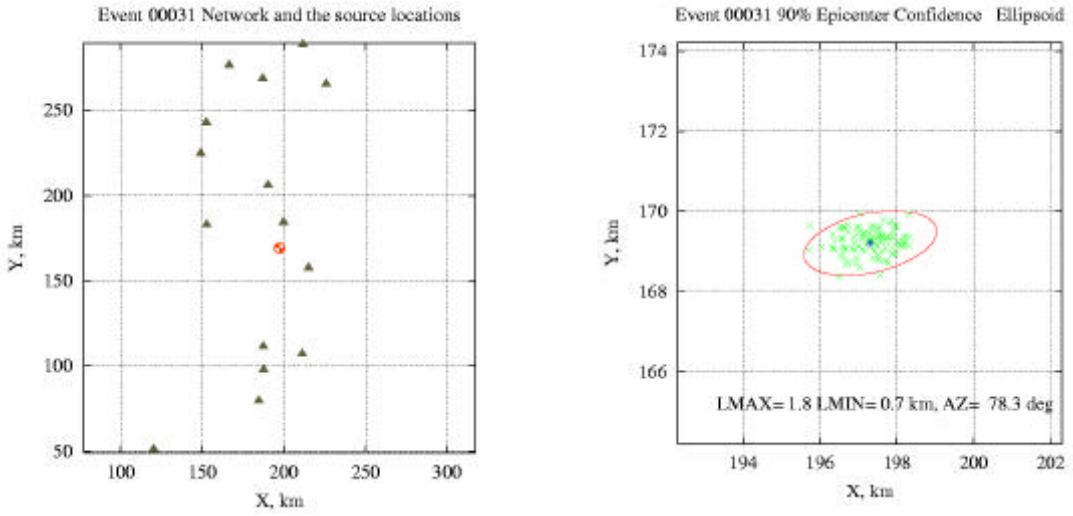


Fig. 1. Map of selected earthquakes with magnitude M_L>3 located within the Israel Seismic Network

Fig. 2. Example of estimating 90% confidence ellipsoid (with axes LMIN, LMAX) for an earthquake 11.03.2000 01:52:31.5. The network configuration used in the estimation is also shown.



Aftershocks of large earthquakes in Turkey

Three catastrophic earthquakes occurred in Turkey in 1998-1999: the first one in Adana and Ceyhan areas (27.06.98, 13:55:52.08, Mw=6.3) (Aktar et al., 2000); the second was close to Izmit (17.08.99, 00:01:39.13, Mw=7.6); and the third was in the Bolu-Duzce area (11.12.99, 16:57:19.5, Mw=7.3) (Ozalaybey et al., 2000). Origin time and magnitude values are from NEIC. The earthquakes were accompanied by a series of strong aftershocks, recorded by the permanent local Golcuk and Cylician networks, as well as by portable stations, deployed after the mainshock (Ito et al., 2001). The dense observations facilitated location computations with a high location accuracy for some aftershocks, thus meeting the GT5 criterion. All the events were observed by the ISN and CSN. Source parameters and waveform data were collected, screened and stored in the project database for the following analysis.

The KOERI and EMSRI (Turkey) seismological institutions delivered source parameters of numerous aftershocks from the local bulletins, with corresponding waveforms. We selected fifteen GT5 candidate events (magnitude > 4), which are referenced in the pIDC REB bulletins, and presented below in Tables 1-2, and Fig. 3. The tables comprise the mainshocks (N1 and N7 of the Table 1 and N2 of the Table 2). The maps show locations of the stations and the events and demonstrate the excellent azimuthal coverage of these sources. Source locations of three of the Izmit events (N1, N3, N4 in Table 1) are within 3 km. The same is true for the two Bolu-Duzce aftershocks (N3 and N4 of Table 2). These data might be of great value for the accurate travel-time estimation and calibration of IMS and other stations.

Samples of the raw data, representing recordings of the Turkish networks, are shown on Figs. 4-7. Figures 1 and 2 exhibit waveforms of an Izmit aftershock at the 3-component BB station ISK, deployed in Istanbul (Fig. 5), and the farther IMS array BRAR, located in Istanbul (see the map on Fig. 3a), where regional phases Pn, Pg and Sg can be found (Fig. 4). Strong S-waves (high S/P ratio) from the Izmit and Bolu-Duzce events, are recorded at ISK and BRAR (see Figs. 4-6). No distinct S-waves onsets and strong wave scattering for the Adana events are observed at Cilician stations (Fig. 7). The scattering is possibly related to the location of the earthquakes and recording stations within the valley, surrounded by mountain structures (see Fig. 3b).

The source parameters of the events are presented in Tables 1-2. Magnitude estimations are taken from the PDE bulletin. Some recording stations (Nst) located at distances less then 100 km are also shown (in parentheses). Prominent P and S first arrivals and a large number of close (r<100 km) stations (more than 10 in most cases), ensure a high (of GT5 rank) accuracy of source location.

Table 1. Selected IZMIT and BOLU-DUZCE earthquakes.

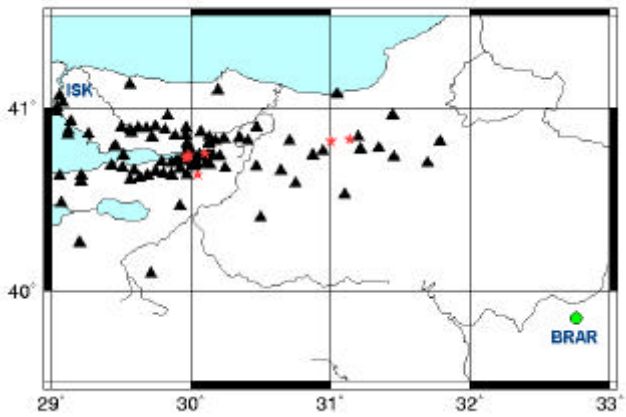
N	O.T.	Lat. deg.	Long. deg.	H, km	M_{PDE}	Nst (R<100 km)	RMS, sec	Az. gap, deg.	Standard location errors			
									Dt_0, sec	dy, km	dx, km	dH, km
1	**990817 00:01:38.7**	**40.729**	**29.966**	**13.3**	**6.7**	**18 (14)**	**0.3**	**75**	**0.96**	**2.6**	**3.4**	**2.7**
2	990817 02:50:47.0	40.638	30.048	1.0	4.5	7 (10)	0.3	257	0.69	3.4	4.7	4.9
3	990831 08:10:50.9	40.747	29.984	8.4	5.2	36 (34)	0.3	66	0.68	1.8	1.2	2.8
4	990831 08:33:24.8	40.740	29.979	10.0	4.6	36 (34)	0.3	97	0.59	1.5	1.0	2.4
5	990913 11:55:29.3	40.753	30.100	16.7	5.9	36 (34)	0.3	60	0.58	1.7	1.4	1.6
6	990917 19:50:6.9	40.753	30.100	13.9	4.5	42 (40)	0.2	60	0.58	1.3	1.1	1.6
7	**991112 16:57:20.8**	**40.830**	**31.138**	**10.0**	**5.5**	**28 (17)**	**0.4**	**?**	**0.83**	**2.7**	**1.7**	**2.6**
8	991119 19:59:12	40.819	31.005	5.6	4.3	35 (20)	0.5	73	1.22	1.6	2.4	3.1

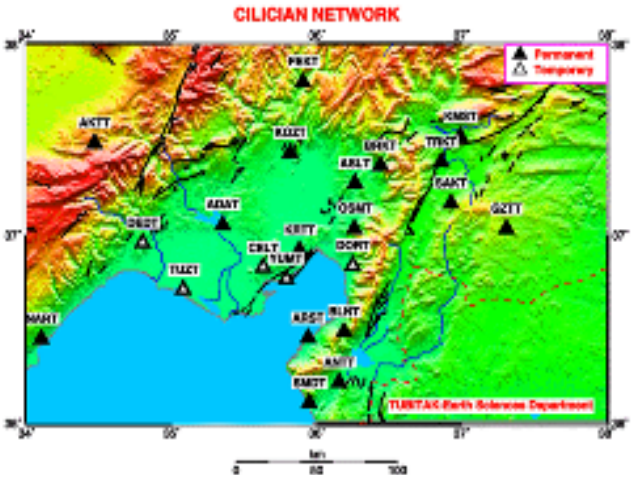
Table 2. Selected ADANA-CEYHAN earthquakes.

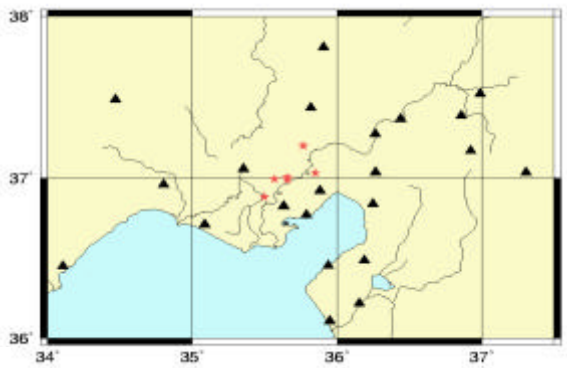
N	O.T.	Lat.	Long.	H, km	M_{PDE}	Nst (R<100 km)	RMS, sec	Az. gap, deg.	Standard location errors			
									dt_0, sec	dy, km	dx, km	dH, km
1	980103 21:15:7.5	37.202	35.766	15.8	4.1	15 (11)	0.4	84	0.94	1.9	2.7	3.7
2	**98062713:55:51.4**	**36.885**	**35.498**	**33.1**	**6.3**	**12 (10)**	**0.2**	**78**	**1.12**	**5.7**	**11.5**	**8.9**
3	980628 03:59:25.9	37.005	35.655	21.2	4.3	13 (9)	0.2	125	0.96	3.0	4.8	6.3
4	980628 15:20:34.7	36.992	35.658	35.1	3.4	14 (8)	0.4	145	1.02	4.0	1.0	3.6
5	980704 02:15:47.9	36.910	35.429	29.5	5.1*	19 (10)	0.8	83	1.92	5.7	5.4	4.5
6	981204 04:59:27.8	36.995	35.568	29.2	4.3	14 (9)	0.3	82	0.91	2.5	2.6	5.0
7	990115 02:04:31.3	37.033	35.850	24.1	4.3	18 (15)	0.4	64	1.1	3.2	3.2	3.9

Golcuk bulletin

Fig. 3. Selected Turkish events (★) and observing stations (▲): (a) Izmit and Bolu-Duzce earthquakes; (b)







Ci*lician network and selected aftershocks of the Adana-Ceyhan earthquake.

Fig. 4. Waveforms of the 17.09.99 Izmit aftershock (M_{PDE}=4.5) at the IMS array BRAR.

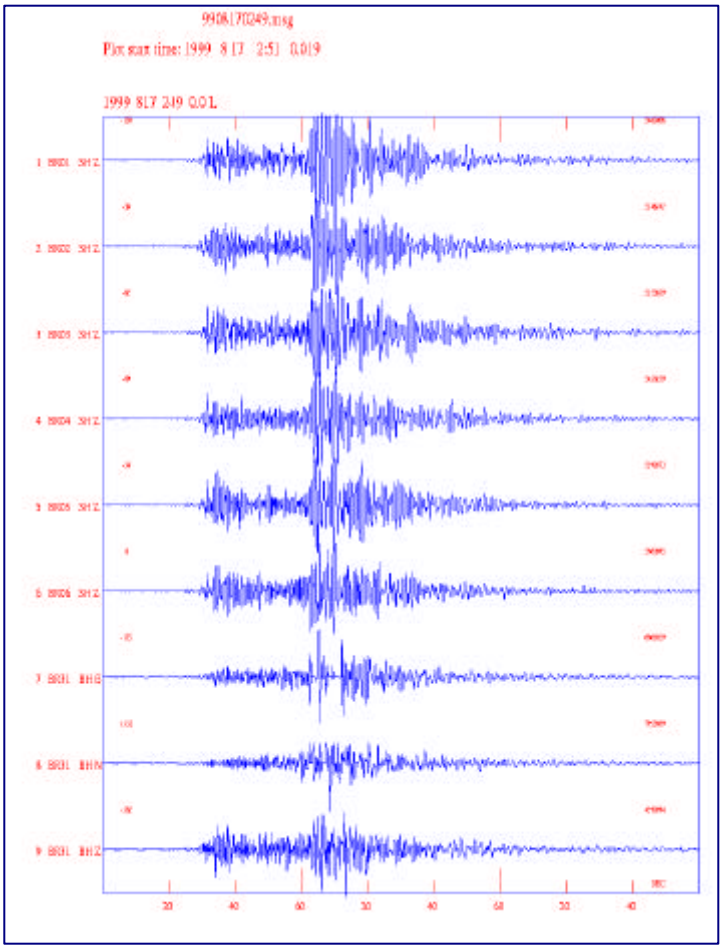


Fig. 5. Waveforms of the 17.09.99 Izmit aftershock (M_{PDE}=4.5) at the ISK BB station.

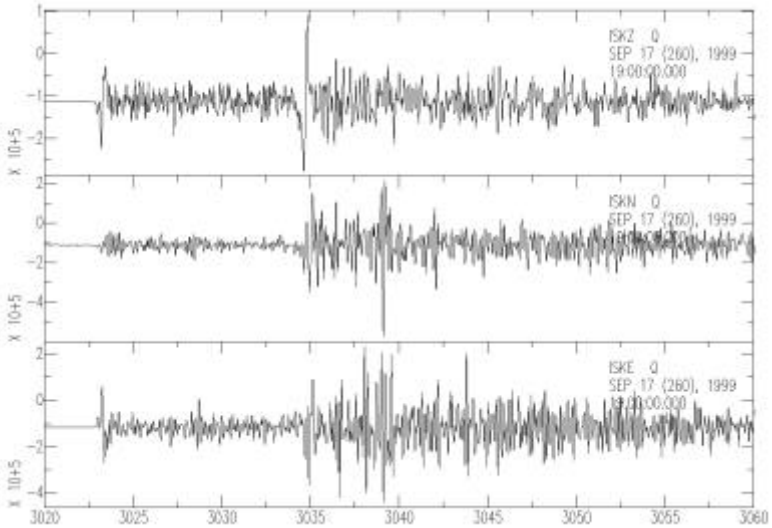


Fig. 6. Waveforms of the Bolu-Duzce aftershock (19.11.99, 19:59, M_{PDE}=4.3) at ISK.

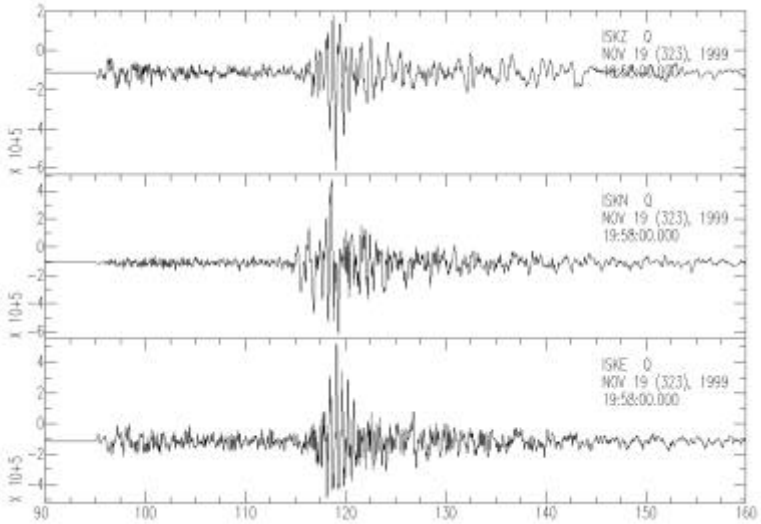
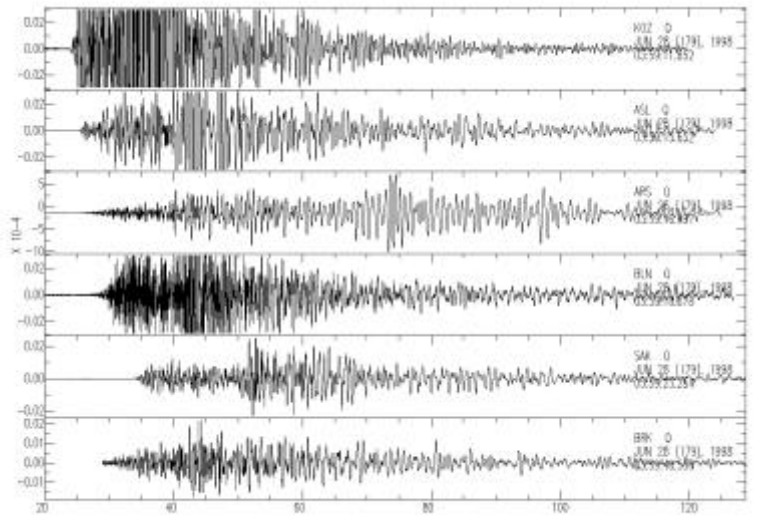


Fig. 7. Waveforms of the Adana aftershock (28.06.98 03:59, M_{PDE}=4.3) recorded at the Cilician network.



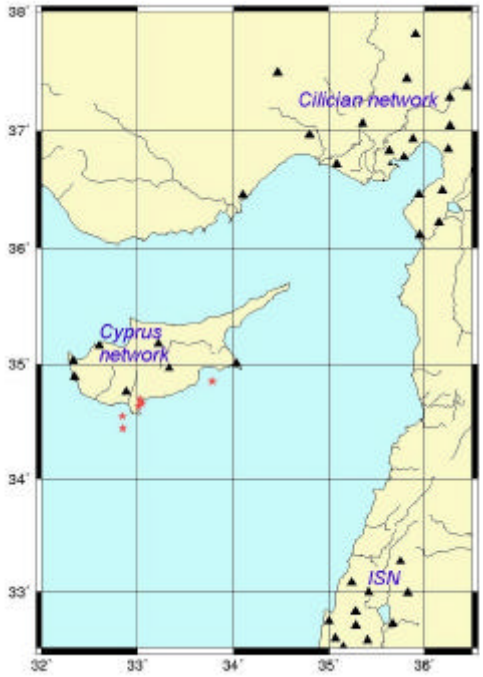
Selected Cyprus Events

From the list of Cyprus earthquakes selected by the GSDC (Cyprus), we found 10 events recorded by all three local networks: the CSN in Cyprus, the ISN in Israel and the Cilician network in Turkey (phase readings are provided by the EMSRI, [Turkey]). Based on estimated standard location errors (see Table 3), we selected six earthquakes (shown on the map in Fig. 8) that meet azimuthal gap and standard error criteria for the GT5 rank. Local duration magnitude M_L is given in the table. Bulletin information and waveform data were collected and screened. Sample seismograms recorded by the CSN are shown in Fig. 9

Table 3. Selected Cyprus events.

N	O.T.	Lat. deg.	Long. deg.	H, km	M_L	Nst (R<100 km)	RMS, sec	Az. gap	Standard location errors			
									dt0, sec	dy km	dx km	dH, km
1	990222 21:06:35.6	34.546	32.844	9	4.7	34 (6)	0.43	182	0.3	1.5	2.4	2.8
2	990729 04:49:44.6	34.439	32.85	9	4.1	38 (6)	0.41	164	0.47	1.5	2.4	4.3
3	990811 01:28:38.7	34.655	33.045	9	4.0	28 (3)	0.66	130	0.51	1.8	3.0	4.3
4	990811 04:27:34.0	34.666	33.035	9	4.0	33 (7)	0.45	129	0.21	1.0	3.0	1.8
5	990811 04:43:25.8	34.693	33.02	9	4.1	25 (6)	0.54	137	0.33	1.3	3.4	2.5
6	990813 15:31:39.1	34.634	33.016	9	4.8	35 (6)	0.8	132	0.34	1.1	2.3	2.0

Fig. 8. Selected Cyprus events, observed by different local networks



Large routine quarry blasts in the Negev and the Galilee (GT2).

We collected data for 23 large (of local magnitude M_L about 3) quarry blasts, including Ground Truth information, which can be related to the GT2 rank. The event location is shown in Fig.1. Origin time, magnitude, coordinates and their corresponding uncertainties (mostly less than 0.3 sec, 0.2 units and 2 km accordingly) are estimated by the Israel Seismic Network. Blast design information is obtained from the quarries and is presented in Table 4. In addition to short-period ISN stations, the blasts were also recorded by the IMS stations EIL and MRNI (or their corresponding surrogate stations). Sample seismograms are shown in Fig. 10.

Table 4. Blast pattern parameters of the selected quarry explosions.

Date	Mag. M_L	Quarry	Total charge, ton	Delays, msec	No. of delays	No. of holes	Hole depth, m	Hole diam., inch
19950322 09:14	2.8	Arad	7.92	25-40	7	111	7	$6^{1/4}$
19950402 08:40	2.9	Arad	9.62	25-40	6	120	7	$6^{1/4}$
19950416 12:08	3.0	Zin	15.5	25-40	5	77	$9\text{-}13^{1/2}$	-
19950426 12:23	2.7	Zin	8.08	25-40	6	64	8	9
19950522 11:56	2.9	Arad	6.50	25-40	-	250	5	$5^{1/8}$
19950523 09:20	2.9	Arad	13.06	25-40	8	110	7	10
19950731 11:14	2.9	Arad	13.26	25-40	8	100	9	$7^{7/8}$
19950803 08:47	2.9	Arad	12.84	25-40	10	96	9	$7^{7/8}$
19950820 12:52	3.0	Arad	12.0	25-40	3	86	9	$7^{7/8}$
19950823 11:49	3.0	Arad	20.6	25-40	20	-	9	-
19970330 08:38	3.0	Oron	20.64	25-40	18	150	9	$7^{7/8}$
19970406 09:39	3.0	Oron	20.0	25-40	11	150	9	$7^{7/8}$
19970521 08:04	2.8	Arad	8.7	25-40	15	87	6.7	$7^{7/8}$
19970609 08:48	2.8	Arad	11.66	25-40	33	90	7	$7^{7/8}$
19970818 09:27	2.9	Arad	7.0	25-40	7	56	9	$7^{7/8}$
19970819 13:51	2.8	Zin	10.0	25-40	8	135	6	$7^{7/8}$
19970820 14:47	3.1	Oron	9.5	25-40	12	98	7	$7^{7/8}$
19970905 07:50	2.9	Oron	13.2	25-40	10	90	8	$7^{7/8}$
19970914 08:28	2.7	Arad	5.92	25-40	5	36	9	$7^{7/8}$
19970915 09:53	2.8	Oron	5.62+4.2	25-40	8+10	47+600	9& 2.5	$7^{7/8}$& $3^{1/2}$
19971223 10:00	2.8	Arad	12.0	25-40	10	90	10	$7^{7/8}\text{-}9^{1/2}$
19980225 09:07	2.8	Arad	11.4	25-40	10	76	9	9
19980705 13:00	2.5	Carmel	8.4	25	12	-	16	4½

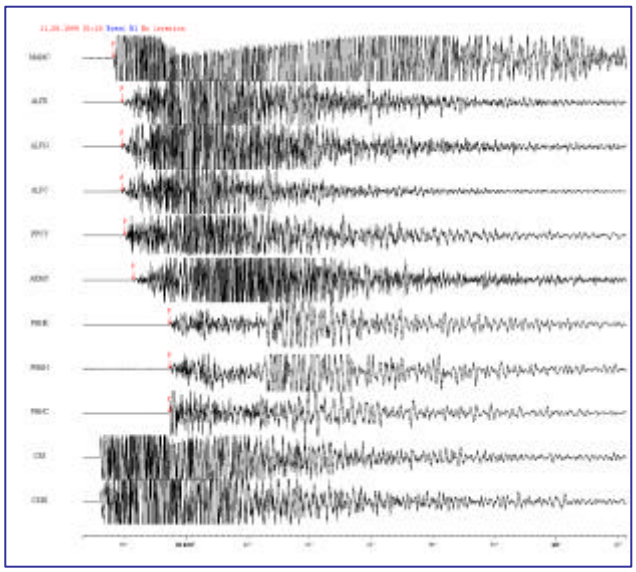


Fig. 9. Waveforms of the Cyprus earthquake (11.08.99 01:28, M_L=4.0) recorded at the Cyprus network

Calibration explosions in the Dead Sea (GT0).

Waveforms from the Dead Sea underwater explosions in Nov. 10, 1999 (2060 kg), and Nov. 11, 1999 (5000 kg), recorded by stations in Saudi Arabia (see Fig. 11 and Table 5), were made available during the RELEMR workshop in Barcelona, May 2001. The records were screened, and a preliminary analysis of the seismograms was made. Waveform samples are presented in Figs. 12 and 13.

Clear regional phases of Pn, Pg and Sg are observed at distances R<500 km (Fig. 12). At remote stations, located at distances 700-1100 km, Pn cannot be observed above the background noise (see Fig. 13). In comparison with the IASPEI91 travel time model, we observe early arrivals of Pg and Sg phases (residuals dt~3-5 sec) (Fig. 13).

Table 5.Selected Saudi Arabia stations with good quality records and observable signals of the Dead Sea explosions

Station	Latitude	Longitude	Altitude, km	Dead Sea expl. site	
				Dist., km	Azim.
QURS	31.3860	37.3240	0.4910	179	95
ALWS	29.3103	35.0650	0.0000	248	188
HAQS	29.0548	34.9297	0.4200	278	190
BDAS	28.4317	35.1014	0.3600	344	185
TBKS	28.2248	36.5485	0.8200	371	163
DBAS	27.2114	35.9773	0.1800	481	174
UMJS	25.2340	37.3119	0.1300	720	165
YNBS	24.3397	37.9922	0.0800	834	162
AFFS	23.9267	43.0005	1.0900	1122	137

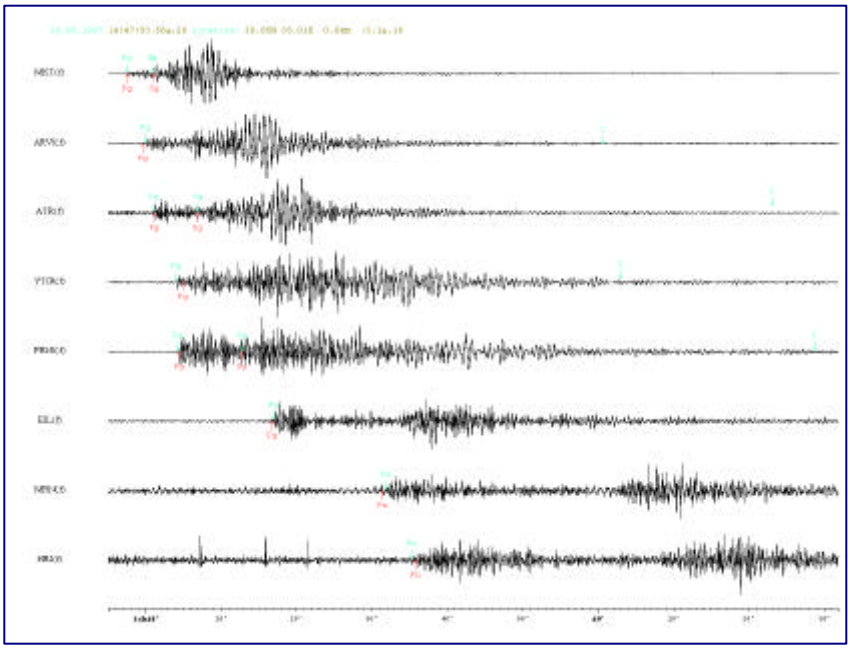


Fig. 10. Sample seismograms of a blast in the Oron quarry, located in the Negev desert, Southern Israel, on Aug. 20, 1997 (M_L=3.1) recorded at short-period stations of the Israel Seismic Network (distance range 17-276 km) including surrogate stations EIL and MRN.

Fig. 11. Location of the Dead Sea shots and selected Saudi Arabia stations

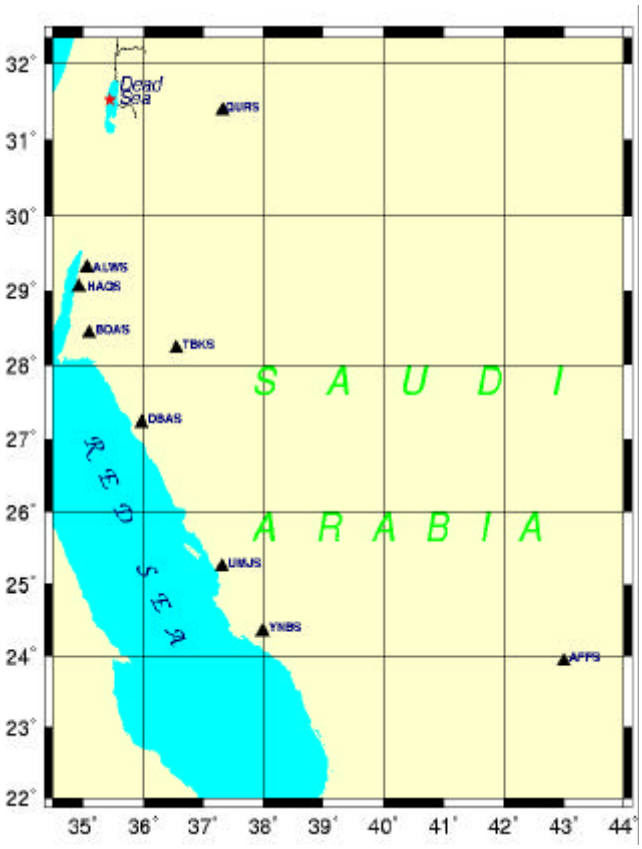
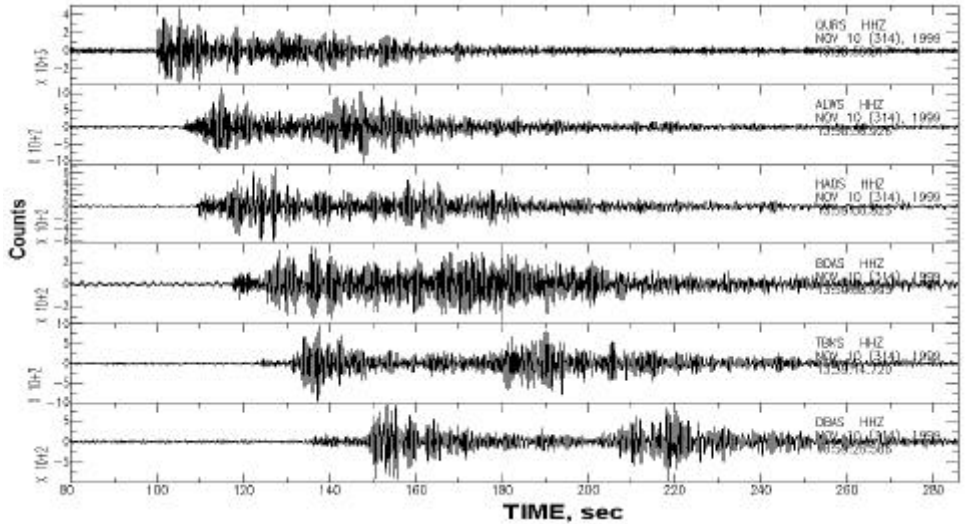


Fig. 12. Vertical seismograms of the second Dead Sea explosion 2060 kg recorded at Saudi Arabia stations in the distance range 179-471 km. Filter 0.5-10 Hz was applied.



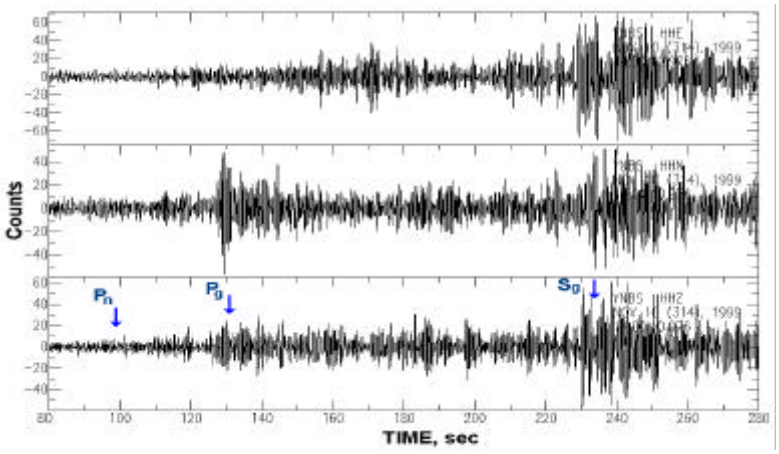


Fig. 13. Three-component seismograms of the second Dead Sea explosion 2060 kg recorded at Saudi Arabia station YNBS, distance 834 km. Filter 1-3 Hz was applied. Arrows show phase arrivals calculated from IASPEI91 model.

CONCLUSIONS AND RECOMMENDATIONS

As the result of joint efforts of the GII (Israel), the KOERI/EMSRI (Turkey), and the GSDC (Cyprus), a database of Middle East-Eastern Mediterranean events is prepared. The database includes: GT2 and GT5 earthquakes in Israel and Cyprus, aftershocks of strong earthquakes in Turkey, routine large quarry blasts (GT2) and controlled explosions (GT0) in Israel. All events were verified in a trustworthy way by a series of relocation experiments, resulting in an improved hypocenter location accuracy.

The elaborated database is intended for: a) calibration of regional IMS stations by verification of travel times and source characterization of local earthquakes and explosions; b) characterization of various regional phases propagation in terms of excitation and attenuation; c) mapping of magnitude thresholds for different observational systems (local networks and subnetworks, and arrays); d) further development and verification of signal processing methods for improvement of detection, location and identification of seismic events in the Middle East and Eastern Mediterranean region.

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